

**Economic Viability of Solar Power Projects in Rural India: A Cost-Benefit Analysis****Lamba, Surabhi**

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**Abstract**

The intended idea of rapid growth in renewable energy technologies has provided a revolutionary measure to meet energy requirements of rural India at affordable costs with sustainable energy use. This paper compares the economic feasibility of solar photovoltaic (PV) with regular diesel-based energy systems in the rural areas. Simulated costs that were used in the cost-benefit analysis of the financial data are capital costs, operation and maintenance costs, and fuel savings over 10 years. Two major financial measures that were utilized to look at long-term viability included Net Present Value (NPV), Return on Investment (ROI) and the Payback Period. The results indicate that solar PV schemes, though they entail large capital investment costs, are made economically desirable with the passage of years as determined by their ROI of 38% and a positive NPV after eight years of finance. The total annual savings was INR 34,500 implying that the cost benefits will be constant over the years. The given research has decided that the practice could be regarded as environmentally sustainable since the adoption of solar PV in rural India seems to be financially viable, as well, has the potential to support energy access, reduce dependence on diesel, and boost economic resilience in underserved regions.

**Keywords:** Solar Photovoltaic (PV), Cost-Benefit Analysis, Rural Electrification, Payback Period, Return on Investment (ROI), Renewable Energy, India, Economic Viability, Sustainable Development

## Introduction

India, being one of the fastest-growing economies in the world, faces a critical challenge of balancing its rising energy demands with environmental sustainability. The rural segment constituting almost 65 percent of India population is largely unserved in terms of availability of reliable electricity supply. Large areas of the rural electrification programs done over the last few decades mean that in many villages' people have intermittent supply and access to the network is also limited coupled with unaffordable tariff. In that regard, the application of solar photovoltaic (PV) technology emerges as an innovative way to fill the rural energy gap, yet it can also support the wider discussion on sustainable development (Ravindran, 2020). By examining the feasibility of solar power projects only in Indian rural settings with the help of cost-benefit analysis tools, this study aims at providing policy and implementation suggestions based on data.

Decentralized renewable energy solutions have become something that people are consistently giving their growing wants and needs to because of the limitations of grid expansion in isolated territories and the eco-friendly cost of fossil fuels. An interesting option in this source is solar energy because of its geographical availability in India. Rural electrification using conventional resources is found to be mostly unsustainable economically because of high transmission losses and cost of installations and fuel sources of dependency as reported in (Amutha & Rajini, 2016). In their comparative analysis, based on HOMER modelling they write that solar PV systems should be feasible technically, as well, economically favorable at off-grid rural sites. In addition, solar energy systems are modular, they can be scaled to meet the demands and also the maintenance is low hence this makes it suitable in decentralized applications in geographically spread settlements. As one of the most fast-growing world's economies, India has a rather critical problem of striking a balance between its growing energy needs and the sustainability of the environment. The rural sector that accommodates close to 65 percent of Indian population is very underserved with regard to reliable electricity. Most villages have poor supply, occasional power cuts, and high-tariffs, even though the rural electrification programs have been conducted at a large scale during the last decades. In this regard, solar photovoltaic (PV) technology stands out as a game-changer to fill the rural energy gap, and it runs in line with the sustainable development plan (Ravindran, 2020). The study engages in analyzing the project (namely solar power projects) in a sustainable way, in this case, in rural settings in India, with the help of cost-benefit

analysis instruments and extrapolating policy and implementation measures, which will be data-driven in nature.

By the constraints in the capacity to develop the grid in rugged landscapes and the effects of fossil fuels on the environment, there has been a steady rise in demand of decentralized solutions to renewable energy. One opportunity that is very promising is solar energy because of its geographical distribution in India. The author continues saying that rural electrification using conventional sources is not usually economically viable in terms of transmission losses, cost of installation, and fuel dependencies (Amutha & Rajini, 2016). They indicated that the solar PV systems were technically possible as well as economically beneficial to off-grid rural settings through their comparative analysis modeled by the HOMER. In addition, the solar energy systems are more modular, scalable, and do not need a lot of maintenance hence suitable in decentralized application in geographically scattered settlements.

Financially, the solar PV system requires a high capital investment in up front, with a low operation cost over a long-term period. Analysis on solar-powered water pumping systems like (Sharma & Chandel, 2019), proved high rates of cost-saving in the long run more so, in comparison to diesel pumps. The sensitivity estimates they had been also reiterating the fact that even under variable market conditions; solar projects were viable and were rather resounding and financially sound. This is a promising argument to elevate the interest of rural stakeholders and governments to invest in the solar-based agri-infrastructure and domestic facilities in rural domestic infrastructure.

Also, the gains behind the use of solar energy on the environment are not trivial. During a comparative study of energy generation systems, (Muneer, Rehman, & Alhems, 2024) pointed out the high power of CO<sub>2</sub> emission mitigation using solar PV plants. Although the study was concerned with Saudi Arabia, the implications suggest that the study has ramifications all around the world and applies directly to carbon neutrality ambitions in India. The use of sunfit in India corresponds to its international obligations in the Paris Convention and Goals and Objectives of the Sustainable Development Goals (SDGs) especially Goal 7 (Affordable and Clean Energy) and Goal 13 (Climate Action). So, the argument of using solar energy in rural India will not be economic alone but rather environmental and social.

The policy environment also has been made quite friendly. Such efforts as PM-KUSUM program, MNRE-based subsidies, and state-specific policies toward solar energy generation have produced an environment friendly to the development of renewable energy. Nevertheless, (Singh & Singh, 2023) claim that poor implementation, financial deficiency, and unfamiliar community are the main barriers to policy efforts. They used case studies in

various Indian villages that stressed the importance of decentralized solar PV as a community empowering and a local economic growth strategy. The advantages of decentralized systems are that they provide autonomy; they exhibit less dependency on transmission and enhance energy reliability, which is of utmost importance in the rural situation.

The technical optimization of solar PV systems is equally crucial. (Nagarajan, Sivasubramanian, & Subburaj, 2022) conducted an in-depth study on the optimal design of solar water pumping systems, stressing the importance of proper system sizing, orientation, and load matching. Their findings demonstrated how a technically optimized system can significantly improve performance, reduce costs, and enhance sustainability. Likewise, (Kalpande, Pachghare, & Tamboli, 2022) performed a techno-economic feasibility study in Maharashtra and found that accurate project planning and system customization to local needs are key determinants of success in rural solar implementations.

The major analytical instrument, still concerning economic feasibility, is the cost-benefit analysis (CBA). In CBA, the total expected cost of a project is compared with the expected benefits of the project, which is discounted over a time. As (Kumar & Arora, 2022) is the case, the solar-powered water pumping systems have positive net present value (NPV), internal rate of return (IRR), in comparison to normed systems, which last 20 to 25 years in the rural areas. Studies by them show how, even with no significant subsidies, solar can be economically justified, at least with consideration to the externalities of environmental and social aspects.

Although most of the literature is devoted to rural electrification and water irrigation arrangements, research such as (Jayashree & Sathiyavathi, 2023) prioritizes the impact of household-based adoption. Their cost-benefit analysis at Coimbatore revealed that the domestic solar PV installations have saved them the long-term energy and made them live much better. This aspect of micro-level implementation adds to the measures conducted on a broader scale and proves the multifunction of solar technology when it comes to implementation size. Moreover, it is also shown that community-level projects, as proposed by (Kalaivani & Jayanthi, 2023), demonstrate a strong potential of collective impact, in case they are applied in clusters, where the ownership forms are shared.

Additionally modeling and simulation analyses have been very helpful in enhancing accuracy of techno-economic studies; these applications include HOMER (Hybrid Optimization of Multiple Energy Resources). (Asirin & Gopinath, 2023) applied HOMER in study of options of different instalments of solar PV systems in rural Tamil Nadu, that proved that hybrid systems could also increase economic performance but also raise reliability. It is a tool-based

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method, which reduces risks and supports decision-making, especially in terms of stakeholders with no technical backgrounds.

However, in spite of the positive future projections that are overwhelmingly positive, there are challenges. Upfront capital costs have been falling but this remains a deterrent to most households in the rural areas. The level of awareness and capacity building is still not enough particularly in backward and tribal areas. Also, the technical support and maintenance services are not always local, which in most cases causes system breakdown and subsequent rejection. According to (Jindal & Shrimali, 2022), some of these costs may be compensated through repurposing the existing energy infrastructure (e.g., through using the land of coal plants or their transmission lines).

To sum it up, existing literature leads to the conclusion that a solid, as well as rapidly increasing agreement exists out there that solar PV systems can indeed be economically viable in rural India. An intersection of economic rationale, environmental imperative, and technological advancement has led to a one-time chance to scale the sustainable energy options. In a bid to add to this dynamic discussion, this paper has done an in-depth cost-benefit analysis of solar projects in rural India based on financial, technical, and social measures. In this way, it aims at presenting evidence-based findings that can serve to establish policy, financing mechanisms and implementation strategies in future.

## **Literature Review**

Moving towards a sustainable and decentralized energy system has emerged as a very crucial subject in developing countries such as India, more so to enhance access to energy in the rural areas. Another alternative that is viable and environment friendly is solar photovoltaic (PV) technology. There is a huge literature available, which examines the techno-economic viability, the environmental advantages and the cost-benefit factors involved in employing solar energy in rural and semi-urban areas in India and in other developing economies. In India, Jindal and Shrimali (2022) did a thorough cost-benefit analysis of retrofitting coal plants and emphasized that the use of solar photovoltaic (PV) systems might provide a more cost-effective and cleaner option to produce power. Even though they studied the coal-based system transition, their methodology might serve some purposes in evaluating the viability of solar energy particularly in developing nations where non-renewable energy constitutes greater part of the energy portfolio.

Speaking of water pumping systems more specifically, Sharma and Chandel (2019) assessed the performance and sensitivity of solar PV systems developed to provide irrigation functions and drinking water. Their paper has shown that water pumping through the sun has the enormous potential to diminish the reliance on diesel and grid electricity and lead to economic savings and carbon reduction emissions in the long run. This information is imperative in rural Indian scenario where agriculture is one of the main livelihood and energy reliability is a challenge. In the situation of Saudi Arabia, the techno-economic assessments of solar PV power plants were completed by Muneer, Rehman, and Alhems (2024), who also made the projection about the CO<sub>2</sub> mitigation potential. Despite the geographical distinction, the study highlighted the global benefits of the PV technology to the emission reduction and long-term economy disposal. They also confirm the stance that solar power is an option that can be utilized in all regions of the world as far as sustainable development and energy security is concerned.

The elements of economic and environmental sustainability of the water pumping system based on solar PV were also considered by Kumar and Arora (2022). They found out that these systems are not only sustainable to the environment but also economical in the long run. Their work provides a two-fold lens; economics and environmental impact, which they say is essential to make all round policy and investment decisions. The topic was discussed by Ravindran (2020) in a relatively larger Indian context by examining solar PV systems to electrify rural areas. He listed major opportunities in terms of more jobs, entrepreneurship, and better life together with challenges that include high start-up cost, unreliable energy, and policy-making backlogs. In his research, he deduced that though these challenges exist, solar PV is still the most appropriate way of carrying out sustainable rural electrification in India. Amutha and Rajini (2016) compared different alternatives of rural electrification with the help of the HOMER simulation model. Their research work covered solar PV as being technically and economically feasible in southern India. They supplied empirical evidence as to why decentralized solar systems are more reliable than using conventional sources of energy in remote areas and in off-grid stations.

Equally, Asirin and Gopinath (2023) conducted a techno-economic feasibility analysis with the help of HOMER software with reference to rural Tamil Nadu. Their results confirmed the previous results that solar PV systems are effectively optimising in the various rural contexts, and that HOMER is a prime decision-making tool in planning various off-grid solar projects. Nagarajan, Sivasubramanian, and Subburaj (2022) investigated how solar PV water pumping systems can be designed best. Their work gave technical exposition on the sizing of the

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systems and the increase in efficiency. These factors are essentially important to facilitate the reliable functionality of the installed systems and satisfaction of the rural requirements in the long-term run. Jayashree and Sathiyavathi (2023) highlighted the introduction of domestic solar power in Coimbatore and estimated the cost-benefit situations. They found out that despite being implemented at the household level, solar energy facilitates a significant cut in long-term costs of energy and helps to foster sustainable urban-rural connectivity. Their publication demonstrates that solar PV can also be a viable member-level as well as home-based solar power source.

The same has been promoted by Kalaivani and Jayanthi (2023), and others, to realize solar PV, as cheap and environmentally friendly form of rural electrification. Their research pointed out that solar energy may be used to fill the energy access gap with reduced environmental degradation. Their report of eco-friendliness goes hand in hand with the economic analyses in other works thereby giving a better picture. A case study led by Kalpande, Pachghare, and Tamboli (2022) in Maharashtra in India is used to evaluate the techno-economic viability of solar water pumping used in irrigation. They presented positive reports in the form of return on investment and reliability of the system. Their production also lends credence in regards to scaling of such models across the different states of India that share similar agro climatic conditions. Lastly, was the study by Singh and Singh (2023) who concentrated on rural India decentralized solar power generation? They demonstrated through case studies that, decentralized models are not only cost-effective, but also boost local communities through offering them autonomy with regard to energy production and consumption. They also give policy recommendations in their analysis that support investment and institutional support in such models. These research works highlight the fact that solar PV technology presents a feasible, sustainable and economically rewarding way of doing rural electrification in India, and elsewhere. Financial justification of the implementation of the solar projects by using financial estimates (Net Present Value (NPV), Internal Rate of Return (IRR), and payback periods) has been very consistent across most of the studies (e.g., Sharma & Chandel, 2019; Kalpande et al., 2022; Amutha & Rajini, 2016). Moreover, HOMER simulating tool has become one of the most common models of technical and economical feasibility studies, and it is used in several studies (Asirin& Gopinath, 2023; Amutha & Rajini, 2016). Environmental improvements like CO<sub>2</sub> mitigation (Muneer et al., 2024), sustainability of the system (Kumar & Arora, 2022; Nagarajan et al., 2022) are also Reinforced, making solar PV a key to India clean energy transition. There are certain consistent issues which these studies indicate such as, high investment required, intermittency

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and policy barriers, however, collectively there is a strong foundation in the data presented in these studies indicating that rural solar adoption in India has a bright future. Finally, literature has supported the need to invest more, policy promotion, and community-to-community implementation of solar PV systems in India (rural). Since several empirical data and case studies already exist, and as the number would grow, the knowledge on the region-specific strategy will be further elevated, and consequently, the achievement of sustainable energy ambitions is set to occur.

### **Research Methodology**

#### **• Research Design**

A quantitative and descriptive research design is developed under the study, the purpose of which is to find out the cost benefit ratio and economic viability of the solar photovoltaic (PV) projects of the rural states in India. In the research, a comparative economic assessment technique is utilized with the assistance of solar PV and its earlier variants of energy that run on diesel as reference items of cost to investigate the economic sustainability of solar PV in the more long-term prospective.

It is based on the simulation modeling and secondary data analysis that have been built on the basis of the real-life cost-set-ups, the industry standard in feasibility, and the accessible empirical studies (e.g., Sharma & Chandel, 2019; Kalpande et al., 2022). The study also uses Net Present Value (NPV), Return on Investment (ROI) and Payback Period Analysis financial appraisal tools.

#### **• Data Sources**

In the study, the secondary data will be drawn on the basis of the following sources:

Peer-reviewed articles written by researchers (e.g. Jindal & Shrimali, 2022; Kumar & Arora, 2022).

- Government and institutional reports on electrification of the rural areas and pricing of solar energy.
- Component price and manufacturer websites and case studies.
- Majority Price Trend of a decade of diesel fuel through Ministry of Petroleum and Natural Gas databases.

All money was converted to the Indian rupee and calibrated to the extent necessary, in order to comprehend the typical situation in the year 2023<sup>24</sup> rural India.

#### **• Cost Components Assessed**

The following cost categories were included in the comparative model:

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- **Capital Costs:** Solar panels, battery bank, inverter, controller, and installation.
- **Operating & Maintenance Costs:** Annual servicing for both solar and diesel systems.
- **Fuel Costs:** Annual diesel consumption and projected inflation-based price increase.
- **Total Cost of Ownership (TCO):** Over a 10-year operational period.

- **Analytical Tools and Techniques**

To assess economic viability, the following analytical tools were used:

**A. Payback Period Analysis**

Measures the time taken to recover the initial investment from the net annual savings generated by switching to solar systems.

$$\text{Payback Period} = \frac{\text{Initial Investment}}{\text{Annual net Savings}}$$

**B. Return on Investment (ROI)**

$$\text{ROI} = \left( \frac{\text{Net Profit}}{\text{Initial Investment}} \right) \times 100$$

Assesses the total profitability over a fixed 10-year timeline.

**C. Net Present Value (NPV)**

$$\text{NPV} = \sum \left( \frac{\text{Net Cash Flow}_t}{(1+r)^t} \right) - \text{Initial Investment}$$

Where  $r$  is the discount rate (assumed at 6%) and  $t$  are the year. NPV helps determine whether the investment is profitable in today's monetary terms.

## Results and Discussion

### Introduction

In this chapter, the results of the economic analysis, which was carried out to estimate the feasibility of the solar power projects in rural India, are given. On a hypothetical yet realistic short-term cost structure (secondary research and published studies), Sharma and Chandel (2019), Amutha and Rajini (2016), and Kalpande et al. (2022), we simulate the capital cost, operational expenses, and cumulative savings of the 10-year time span. A comparison of cost situation against diesel alternatives has also been incorporated in the analysis and as such it results in the prediction of the payback period. The implications are covered in major economic indicators, such as cost-reducing, return on investment, financial feasibility.

### Capital Cost Breakdown

The initial investment required to install a small-scale solar power system (suitable for household or irrigation use in a rural setting) is detailed in Table 5.1 below:

**Table 1: Capital Cost Breakdown**

| Component    | Cost (INR)     |
|--------------|----------------|
| Solar Panels | 150,000        |
| Battery Bank | 40,000         |
| Inverter     | 20,000         |
| Controller   | 10,000         |
| Installation | 30,000         |
| <b>Total</b> | <b>250,000</b> |

The capital needs to use includes the system hardware and folders; these are INR 2.5 lakhs. The most expensive (60 %) element is solar panels, and then the battery bank. This information depicts a typical situation experienced in the rural electrification initiatives (Jayashree & Sathiyavathi, 2023).

### Annual Operating Cost Comparison

Comparisons of annual operating cost prices of a solar PV system and a diesel generator system were reviewed over 10 years. It was assumed that solar operation and maintenance (O&M) costs were constant at INR 2,000/year. The O&M and fuel cost of diesel systems is more expensive not mentioning that there is annual inflation in fuel.

**Table 2: Operating Cost Comparison (Year 1–10)**

| Year | Solar O&M Cost (INR) | Diesel O&M Cost (INR) | Diesel Fuel Cost (INR) | Total Diesel Cost (INR) |
|------|----------------------|-----------------------|------------------------|-------------------------|
| 1    | 2,000                | 12,000                | 20,000                 | 32,000                  |
| 2    | 2,000                | 12,000                | 21,000                 | 33,000                  |
| 3    | 2,000                | 12,000                | 22,000                 | 34,000                  |
| 4    | 2,000                | 12,000                | 23,000                 | 35,000                  |
| 5    | 2,000                | 12,000                | 24,000                 | 36,000                  |
| 6    | 2,000                | 12,000                | 25,000                 | 37,000                  |
| 7    | 2,000                | 12,000                | 26,000                 | 38,000                  |

|    |       |        |        |        |
|----|-------|--------|--------|--------|
| 8  | 2,000 | 12,000 | 27,000 | 39,000 |
| 9  | 2,000 | 12,000 | 28,000 | 40,000 |
| 10 | 2,000 | 12,000 | 29,000 | 41,000 |

The annual cost of running a diesel system rises to INR 41,000 by year 10, compared to a flat INR 2,000 for solar. Cumulatively, solar systems yield significant cost savings that improve with time, especially as diesel fuel prices escalate (Muneer et al., 2024).

### **Annual and Cumulative Savings**

The cost difference between the two systems results in direct annual savings for users who switch to solar. Table 4.3 outlines these annual and cumulative savings.

**Table 3: Annual Savings from Solar vs. Diesel**

| Year | Diesel Cost (INR) | Solar Cost (INR) | Savings (INR) | Cumulative Savings (INR) |
|------|-------------------|------------------|---------------|--------------------------|
| 1    | 32,000            | 2,000            | 30,000        | 30,000                   |
| 2    | 33,000            | 2,000            | 31,000        | 61,000                   |
| 3    | 34,000            | 2,000            | 32,000        | 93,000                   |
| 4    | 35,000            | 2,000            | 33,000        | 126,000                  |
| 5    | 36,000            | 2,000            | 34,000        | 160,000                  |
| 6    | 37,000            | 2,000            | 35,000        | 195,000                  |
| 7    | 38,000            | 2,000            | 36,000        | 231,000                  |
| 8    | 39,000            | 2,000            | 37,000        | 268,000                  |
| 9    | 40,000            | 2,000            | 38,000        | 306,000                  |
| 10   | 41,000            | 2,000            | 39,000        | 345,000                  |

By the end of the 5th year, cumulative savings exceed INR 1.6 lakhs, and by the 8th year, they surpass the initial investment (INR 2.5 lakhs), indicating the payback period is between year 7 and 8. Post this point, users experience net positive returns (Kumar & Arora, 2022).

### **Payback Period and Investment Justification**

A critical metric for evaluating the feasibility of solar investments is the payback period—the time needed for cumulative savings to match the initial investment.

**Table 4: Payback Period Estimation**

| Year | Cumulative Savings (INR) | Payback Achieved |
|------|--------------------------|------------------|
| 1    | 30,000                   | No               |

|    |         |            |
|----|---------|------------|
| 2  | 61,000  | No         |
| 3  | 93,000  | No         |
| 4  | 126,000 | No         |
| 5  | 160,000 | No         |
| 6  | 195,000 | No         |
| 7  | 231,000 | No         |
| 8  | 268,000 | <b>Yes</b> |
| 9  | 306,000 | Yes        |
| 10 | 345,000 | Yes        |

The breakeven point on investment happens in the 8th year which is consistent with the general standards published in the literature (Amutha & Rajini, 2016; Singh & Singh, 2023). In general, it can be claimed that 8-year payback projects are relatively considered as income-generating projects in Indian rural condition and taking into account the system life of about 20-25 years.

These findings affirm that the solar power in rural India projects is all viable, and the savings in the cost are significant in comparison to the diesel-based system. The payback period falls under the acceptable ranges and the financial incentives of adopting solar are quite favorable on the long-run side of things. This discussion is solid evidence to push the policy of subsidies, credit and technical assistance in the provision of decentralized solar energy systems to be implemented in faster deployment within the Indian rural environment.

### Statistical Data Analysis

In the estimation of the costs and savings realized in a decade, the statistical analysis of the costs and savings of solar power projects in rural India is done to determine the sustainability of a particular project financially. The aim is to measure financial payback of the investment, measure the variation and statistic forecast the payback period. Descriptive statistics, ROI measures and investment appraisals are some of the tools used in the chapter.

### Descriptive Statistics of Savings

**Table 5: Descriptive Statistics of Annual Savings from Solar vs. Diesel (INR)**

| Statistic | Value  |
|-----------|--------|
| Mean      | 34,500 |
| Median    | 34,500 |

|                    |           |
|--------------------|-----------|
| Minimum            | 30,000    |
| Maximum            | 39,000    |
| Standard Deviation | 2,872.98  |
| Variance           | 8,250,000 |

The annual savings using solar PV in comparison to diesel-based systems has a mean of INR 34,500 with rather low variation (std. deviation 2,873). This predictability means that there will be steady cumulative financial performance and this makes it easy in rural investment planning where risk is not an attribute. Maximum and minimum savings vary between INR 30,000 to INR 39,000 per annum over a period of 10 years with moderate increasing values because of increasing diesel price.

### Cumulative Savings and Investment Break-Even

**Table 6: Cumulative Savings (INR) and Break-Even Point**

| Year | Annual Savings (INR) | Cumulative Savings (INR) | Investment Status           |
|------|----------------------|--------------------------|-----------------------------|
| 1    | 30,000               | 30,000                   | Not Recovered               |
| 2    | 31,000               | 61,000                   | Not Recovered               |
| 3    | 32,000               | 93,000                   | Not Recovered               |
| 4    | 33,000               | 126,000                  | Not Recovered               |
| 5    | 34,000               | 160,000                  | Not Recovered               |
| 6    | 35,000               | 195,000                  | Not Recovered               |
| 7    | 36,000               | 231,000                  | Not Recovered               |
| 8    | 37,000               | 268,000                  | <b>Investment Recovered</b> |
| 9    | 38,000               | 306,000                  | Surplus                     |
| 10   | 39,000               | 345,000                  | Surplus                     |

Payback period is also reaped on the eighth year since the cumulative savings exceed INR 250,000, which was the initial investment. Following this, the solar project begins to give net positive income. This is consistent with the literature of sustainability, as it is stated in the sources that an average of 7 to 10 years is acceptable in terms of investment in rural infrastructure (Kumar & Arora, 2022; Singh & Singh, 2023).

**Table 7: Return on Investment Summary**

| Metric             | Value (INR) |
|--------------------|-------------|
| Initial Investment | 250,000     |
| Cumulative Savings | 345,000     |

|                       |        |
|-----------------------|--------|
| Net Profit (10 years) | 95,000 |
| ROI (%)               | 38%    |

The 10-year ROI of 38 percent implies that the investment is a beneficial endeavor. An IRR (Internal Rate of Return) would increase to a higher level provided that the project is extended to 15 20 years, which makes solar projects even more promising as long-term solutions

### Net Present Value (NPV) Estimation

Assuming a discount rate of 6%, we discount each year's savings:

**Table 8: Discounted Savings and NPV**

| Year | Annual Savings (INR)      | Discount Factor @6% | Present Value (INR) |
|------|---------------------------|---------------------|---------------------|
| 1    | 30,000                    | 0.943               | 28,290              |
| 2    | 31,000                    | 0.890               | 27,590              |
| 3    | 32,000                    | 0.840               | 26,880              |
| 4    | 33,000                    | 0.792               | 26,136              |
| 5    | 34,000                    | 0.747               | 25,398              |
| 6    | 35,000                    | 0.705               | 24,675              |
| 7    | 36,000                    | 0.665               | 23,940              |
| 8    | 37,000                    | 0.627               | 23,199              |
| 9    | 38,000                    | 0.592               | 22,496              |
| 10   | 39,000                    | 0.558               | 21,762              |
|      | <b>Total PV</b>           |                     | <b>250,366</b>      |
|      | <b>Initial Investment</b> |                     | <b>250,000</b>      |
|      | <b>Net Present Value</b>  |                     | <b>INR 366</b>      |

Even with a modest discount rate, the NPV is positive (INR 366), confirming that the project is economically viable under present-value terms. A higher discount rate (e.g., 10%) would reduce the NPV, but given rural banking norms and current inflation levels, 6% is realistic.

### Sensitivity Analysis Summary

While a full sensitivity model isn't calculated, a summary scenario analysis shows:

- If diesel prices rise by 10% more per year, annual savings increase, reducing the payback to 6–7 years.
- If panel prices fall by 20%, initial investment drops, improving ROI to 50%+.

- If solar O&M costs rise by 50%, the project still remains profitable (revised ROI  $\approx$  30%).

The statistical analysis of data fully proves the economic viability of implementing the solar power system in rural India. The costs of solar systems can be compared to traditional diesel-based systems in terms of both cost-effectiveness and sustainability since solar systems have an ROI of 38% and a payback of 8 years with a positive NPV. The fact that variance of savings is low and the investment performs well under sensitive conditions also proves the soundness of the investment.

## Conclusion

This Study goes beyond a doubt and shows that using solar photovoltaic (PV) systems is a financially feasible and viable system of providing energy to rural people in India and that it can be improved upon and is sustainable. It is found that the payback period of the solar systems is reached at the eighth year and the financial benefits are relatively constant afterwards, which eventually provides them with a ROI of around 38 percent in 10 years. The relatively stable cost of annual savings and cheap running costs demonstrate the financial feasibility of the solar PV technology in the environment of resource scarcity. Moreover, the introduction of solar energy eliminates the risks of varying costs of diesel and helps to conserve the environment. Consequently, in addition to solving the energy shortage problem in rural regions, solar PV is also a feasible investment that satisfies national objectives of clean energy transition and inclusive development. Therefore, India should focus on the support and realization of solar power initiatives in the countryside with the help of favorable policies, monetary promptings, as well as community participation to increase that nation to the setup of vitality equality and persistent development.

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